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HALON FLIGHTLINE EXTINGUISHER EVALUATION:
DATA SUPPORTING STANDARD DEVELOPMENT

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This evaluation of flightline fire extinguishers has been conducted to determine minimum performance criteria for assessing the capability of fire extinguishing agents to suppress two specific aircraft engine fires; three dimensional flowing fuel fires in the aircraft tail pipe and engine nacelle fires that can be fought through the access panel. This test series documented performance of 150 lb fire extinguishers containing Halon 1211 for extinguishing hidden and running fuel fires. An F-100 engine nacelle mockup was used to evaluate the full extinguishment times and amount of extinguishing agent used on a series of twenty aft engine and pool fires of 100-ft2 and ten access panel fires. The test series data was successfully used to develop a consistent, repeatable test procedure with pass/fail criteria for three dimensional and hidden fires through the rear engine and the access panel. The resulting document provides the performance standard for assessing alternative agents to determine suitability for use by USAF personnel in support of flightline fire extinguishers with the primary mission of rescue and fire suppression during aviation related incidents.

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Abstract

This evaluation of flight line fire extinguishers has been conducted to determine minimum performance criteria for assessing the capability of fire extinguishing agents to suppress two specific aircraft engine fires; three dimensional flowing fuel fires in the aircraft tail pipe and engine nacelle fires that can be fought through the access panel. This test series documented performance of 150 lb fire extinguishers containing Halon 1211 for extinguishing hidden and running fuel fires. An F100 engine nacelle mockup was used to evaluate the full extinguishment times and amount of extinguishing agent used on a series of twenty aft engine and pool fires of 100-ft^2 and ten access panel fires. The test series data was successfully used to develop a consistent, repeatable test procedure with pass/fail criteria for three dimensional and hidden fires through the rear engine and the access panel. The resulting document provides the performance standard for assessing alternative agents to determine suitability for use by USAF personnel in support of flight line fire extinguishers with the primary mission of rescue and fire suppression during aviation related incidents.

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Background

No official document is in place that establishes the performance standards for flight line fire extinguishers against three dimensional (flowing fuel) fires. US Air Force flight line aircraft fire protection must employ a "clean", 3-dimensional extinguishing agent to avoid harm to jet engines and to effectively extinguish hidden fires.

Recently, a vendor approached the United States Air Force claiming that current Compressed Air Foam (CAF) technology can meet or exceed USAF fire protection requirements at a lower cost than Halon 1211, the currently used standard. The vendor also proposed use of performance standards in lieu of agent/equipment specific standards for new procurements.

Using reliable test protocol the Air Force Research Laboratory evaluates potential clean 3-D fire fighting agents. Agents are tested against flowing fuel fires in F-100 engine mockup on pavement surface. The agent must extinguish both internal engine fire and surface fire.

Test protocol is necessary to ensure that flight line fire extinguishers meet the operational requirements. While no requirement document exists, interviews with experienced Air force firefighters have defined two primary scenarios, nacelle fires fought through access panels and aft engine fires fought from the tail of the aircraft. These scenarios have been reviewed with the Air Force Fire Panel, 11Jan02, and were accepted as valid. Any specification must ensure no increased risk to maintenance personnel, flight crew, (AFI-32-7086) or aircraft and maintain the ability to avoid Depot Maintenance following fire extinguisher application (T.O.2J-F100-46-2).

Purpose

The test series is required to develop a performance standard for flight line fire extinguishers. The standard provides for evaluating alternative agents to determine suitability for use by USAF personnel in support of flight line fire extinguishers with the primary mission of rescue and fire suppression during aviation related incidents. The plan establishes criteria, procedures, safety requirements, and responsibilities for conducting research testing for characterizing the performance standards required to put out 3-dimensional engine fires without obvious damage to the system or increased risk to the aircraft crew and maintenance personnel. The data obtained from the testing provides recommendations for testing firefighting agents on jet engines.

Scope

The tests establish data for development of a Performance Standard for Flight Line Fire Extinguishers. The Performance Standard includes requirements to extinguish fires occurring within the engine nacelle through provided access ports and to extinguish

pooled or flowing fuel tail pipe fires without increasing the risk to maintenance personnel, flight crew, or aircraft and maintaining the ability to avoid Depot Maintenance following fire extinguisher application. This project provides a standard for the experimental testing of fire fighting agents on 3D simulated engine systems.

These tests evaluated the following:

- Operational adequacy for flight line fire extinguishers on engine fires including:
- 20 Aft Engine Fires with flowing fuel in theF100 engine nacelle mockup with 100 ft2 static pool fires
- 10 Access Panel Fires with flowing fuel

Fire Scenarios

Two fire scenarios were used for developing a Minimum Performance Standard for Flightline Fire Extinguishers. These two specific aircraft engine fires occur frequently on the flight line. The extinguisher must effectively extinguish fuel in a flowing state (commonly called 3-dimensional or flowing fuel fires) expected in engine tail pipe fires. Also, the extinguisher must apply agent through engine access ports to penetrate and extinguish fires occurring within the engine nacelle.

Aft Engine Fires

Halon 1211 fire extinguishers regularly extinguished the tail pipe fires with pool and running fuel. Of 20 fires, 18 were fully extinguished. Time to full extinguishment ranged from 8.75 to 50.93 seconds, averaging 16.25 seconds per fire. An average of 67.6 pounds of halon was used, ranging from 45.9 to 112.6 pounds.

Access Panel Fires

Eighty percent of the access panels were completely extinguished within a range of 8.18 to 46.16 seconds, averaging 17.29 seconds per fire. The average amount of agent used was 81.8 pounds, ranging from 57 to 131.95.

Introduction

Background

No official document is in place that establishes the performance standards for flight line fire extinguishers. Flight line fire extinguishers are the first line of defense on real or suspected engine fires. US Air Force flight line aircraft fire protection must employ a "clean", 3-dimensional extinguishing agent to avoid harm to jet engines and to effectively extinguish hidden fires.

Halon 1211 has been long recognized as the best agent for this task. Past agents included carbon dioxide, which produces thermal shock, and Halon 1011, which is less effective and has a higher toxicity than Halon 1211. Firefighting foams have not proven to be effective 3-D firefighting agents on aircraft engine fires and produce corrosive residues. Therefore, engines that ingest these foams require removal from the aircraft and subsequent depot corrosion inspection (reference T.O. 2J-F100-42-2, WP 012 00).

Recently, a vendor approached the United States Air Force claiming that current Compressed Air Foam (CAF) technology can meet or exceed USAF fire protection requirements at a lower cost than Halon 1211. These "clean agent" air foam fire extinguishers would replace the current Halon 1211 flight line extinguishers. The vendor also proposed use of performance standards in lieu of agent/equipment specific standards for new procurements.

There is no existing test document for flight line fire suppression system performance for three dimensional (3-D) fire fighting capability. However, the Air Force Research Laboratory has test protocol to evaluate potential clean 3-D fire fighting agents. Agents are tested against flowing fuel fires in F-100 engine mockup on pavement surface. The agent must extinguish both internal engine fire and surface fire. This protocol has been used to evaluate many proposed clean agents, including C_6F_{14} and CF_3I.

Test protocol is necessary to ensure that flight line fire extinguishers meet the operational requirements. A specification for 150lb Halon 1211 exists that requires extinguishment of 600 sq. ft. (UL 30A 240BC) pool fire, but there is no specification for extinguishing 3-D fires. While no requirement document exists, interviews with experienced Air force firefighters have defined two primary scenarios, nacelle fires fought through access panels and aft engine fires fought from the tail of the aircraft. These scenarios have been reviewed with the Air Force Fire Panel, 11Jan02, and were accepted as valid. Any specification must ensure no increased risk to maintenance personnel, flight crew, (AFI-32-7086) or aircraft and maintain the ability to avoid Depot Maintenance following fire extinguisher application (T.O.2J-F100-46-2).

Purpose

The test series is required to develop a performance standard for flight line fire extinguishers. The standard provides for evaluating alternative agents to determine suitability for use by USAF personnel in support of flight line fire extinguishers with the primary mission of rescue and fire suppression during aviation related incidents. The plan established criteria, procedures, safety requirements, and responsibilities for conducting research testing for characterizing the performance standards required to put out 3-dimensional engine fires without obvious damage to the system or increased risk to the aircraft crew and maintenance personnel. The data obtained from the testing provides recommendations for testing fire fighting agents on jet engines.

Scope

The tests establish data for development of a Performance Standard for Flight Line Fire Extinguishers. The Performance Standard includes requirements to extinguish fires occurring within the engine nacelle through provided access ports and to extinguish pooled or flowing fuel tail pipe fires without increasing the risk to maintenance personnel, flight crew, or aircraft and maintaining the ability to avoid Depot Maintenance following fire extinguisher application. This project provides a standard for the experimental testing of fire fighting agents on 3D simulated engine systems.

These tests evaluated the following:

- Operational adequacy for flight line fire extinguishers on engine fires including:
- 20 Aft Engine Fires with flowing fuel in theF100 engine nacelle mockup with 100 ft2 static pool fires
- 10 Access Panel Fires with flowing fuel

Methods, Assumptions and Procedures

Test Fixture

The F-100 engine nacelle test fixture was developed in response to the inability to determine detailed locations of engine fires. The test fixture is constructed according to the design published previously[iii]. Overall test responsibility rests with the Air Force Research Laboratory (AFRL/MLQD), Deployed Base Systems Branch Test Director.

The F100 engine nacelle mockup has baffles representative of engine nacelle obstacles and voids. Two-inch stainless steel strips alternate in two layers four inches apart. Four thermocouples are used for fixture temperature control, against the walls at the fore end, the aft end, and the center, plus one for ambient temperature in the center. Beneath the test fixture is a concave concrete test surface that is 11 feet in diameter, with center 1 foot diameter circle 3 inches lower than the rim.

Fuel is flowed through the mockup at four gallons per minute through FullJet Maximum Free Passage Spray Nozzles. There are three of these nozzles located in the test fixture.

Nozzle 3 was used to run fuel for the pre-heat phase of the test. The fuel was ignited and burned until the inside thermocouple read approximately 850 degrees. At this point the fuel flow was stopped and the fire was allowed to self extinguish. The temperature continues to increase as the metal absorbs heat. When the metal cools back down to 450 degrees, the fuel is turned on again for the actual test event.

For an aft engine running fuel pool fire, nozzles 2 and 3 run 25 gallons of fuel through the aft engine and into the concrete pan underneath the fixture, creating a pool. After this pool is complete the surface of the fuel is ignited. A 15 second pre-burn allows for the full pool and engine nacelle to become engulfed. The firefighter uses the fire extinguisher to approach and extinguish the pool fire and aft engine area.

The concentric tube design provides the hidden fire space for the Access Panel Test. After the preheat phase, Nozzle 1 is used to spray fuel into the engine nacelle. The fuel is immediately ignited and the 15 second pre-burn begins. The firefighter uses the fire extinguisher to penetrate and extinguish the engine nacelle.

Fire Extinguishers

Standard 150 lb flightline fire extinguishers containing Halon 1211 were used. This is a wheel-mounted fire extinguisher with a 150-pound capacity. It is manufactured by Amerex Corporation, part number 03496, and is suitable for use as a flight line fire extinguisher. The extinguishers were weighed immediately before and after each fire to determine the amount of agent used. Full extinguishment times were recorded. Extinguishers were serviced in between fires per T.O.13F4-4-121.

Firefighter Qualifications

All AFRL Fire Research firefighters are retired Air Force firefighters, with a minimum of 25 years of experience. All professional training in aircraft rescue and firefighting was received from the Air Force.

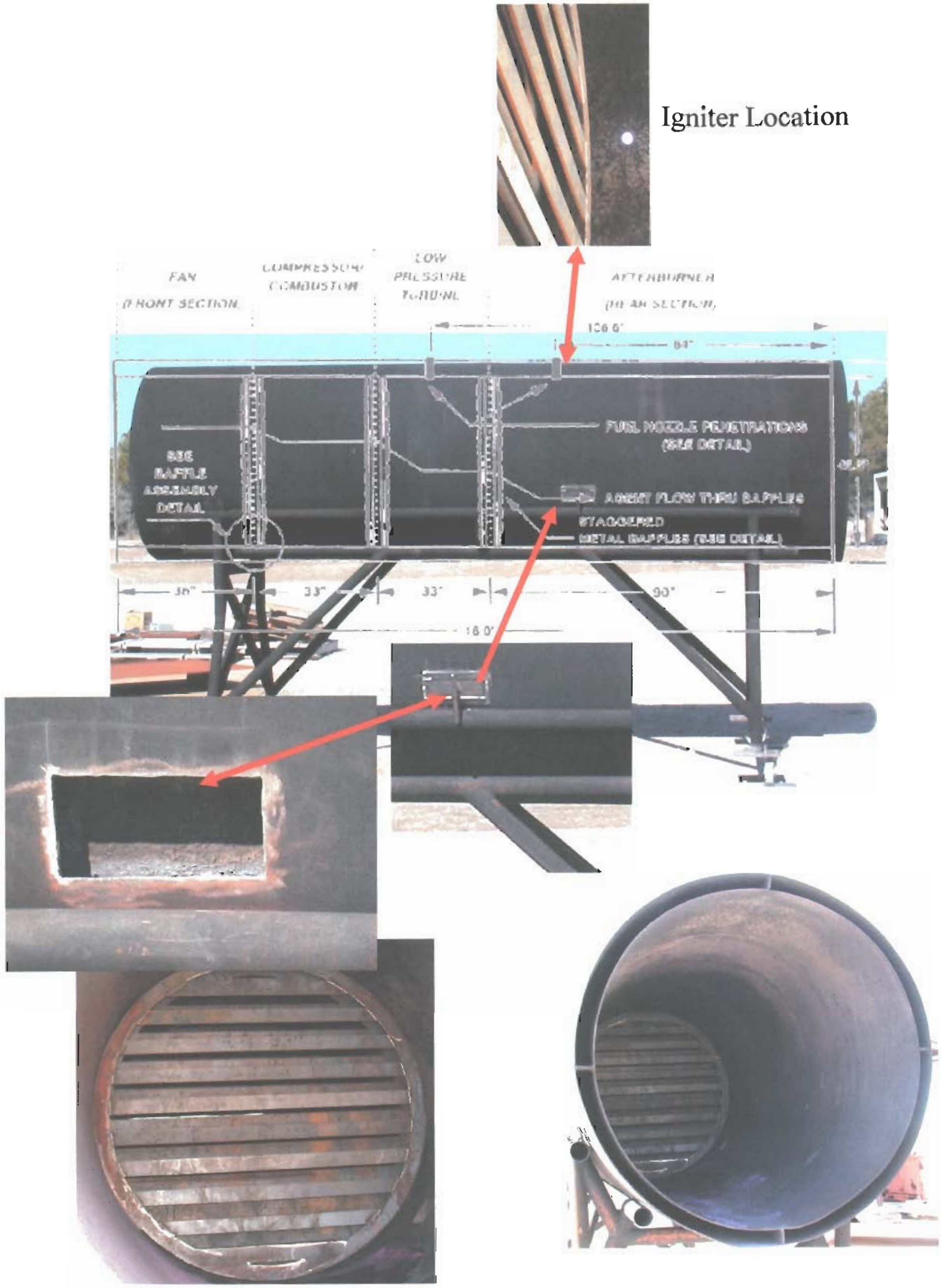

Figure 1. Engine Nacelle Mockup

Fire Scenarios

Aft Engine Fires

Description

The aft end of the test fixture was centered over the concrete pan so that the running fuel flows into the concave pool. The test fixture is lined up with the direction of the wind so that the wind travels from the back to the front of the fixture. When the test fixture reaches 450 degrees, JP-8 jet fuel is sprayed through nozzles 2 and 3 to fill the pool with 25 gallons. The extinguishers were fully serviced prior to each fire. A propane torch was used to ignite the JP-8 and a pre-burn of 15 seconds was conducted to assure full involvement of the fuel in the fire area. The firefighter was given a ten second countdown, at which time a steady attack mode was used to extinguish the fire.

Time to extinguishment was based on complete extinguishment of the pool fire and the fire inside the rear of the text fixture.

Criteria for Success

This test series did not correlate to any existing NFPA requirements; therefore, no maximum extinguishment times were established. The test was conducted to provide an estimation of current flight line fire extinguisher performance.

The series of tail pipe fires were used to gather data to develop performance parameters for flightline fire extinguishers. Data points for each test included type of fire, extinguisher number, wind speed, outside temperature, four thermocouple temperatures, amount of agent used, and full extinguishment time. This data was recorded except for the inside thermocouple reading for the first 5 tests. The data collected is adequate for determining pass-fail criteria.

Access Panel Fires

Description

With the access panel fires the aft end of the test fixture is centered so that the access panel is also located over the concrete pan. The test fixture is lined up with the direction of the wind so that the wind travels from the back to the front of the fixture. When the test fixture reaches 450 degrees, JP-8 jet fuel is sprayed through nozzle 1 into the engine nacelle. The extinguishers were fully serviced prior to each fire. A propane torch was used to ignite the JP-8 and a pre-burn of 15 seconds was conducted to assure full involvement of the fuel in the fire area. The firefighter was given a ten second countdown, at which time a steady attack mode was used to extinguish the fire.

Time to extinguishment was based on complete extinguishment of the fire inside the text fixture.

Criteria for Success

This test series did not correlate to any existing NFPA requirements; therefore, no maximum extinguishment times were established. The test was conducted to provide an estimation of current flight line fire extinguisher performance.

The series of tail pipe fires were used to gather data to develop performance parameters for flightline fire extinguishers. Data points for each test included type of fire, extinguisher number, wind speed, outside temperature, four thermocouple temperatures, amount of agent used, and full extinguishment time. This data was recorded except for the inside thermocouple reading for the first 3 tests. The data collected is adequate to determine pass-fail criteria.

Results and Discussion

Fire Scenarios

A combination of 20 aft engine and 10 access panel fires were conducted over eight business days. Weather conditions varied for the days of aft engine testing. Temperatures were as low as 44° and up to 77°, with winds ranging from 0-8 mph, with one test at 18.4 mph. Weather conditions for the days of access panel testing were consistent, with temperatures ranging from 66° to 73°. Wind conditions varied between 0-8.3 mph, with one test at 10.4 mph.

Time Data Sources

Extinguishment times were collected from two sources:

- From camera 1.
- From camera 2.

Differences in full extinguishment times can be attributed to position relative to the fire. An average of the time sources are considered the official times for full extinguishment.

Aft Engine Fires

90% of the fires were extinguished. All but one of these fires were extinguished within 30 seconds. Fires averaged 16.25 second extinguishment and 67.6 pounds of halon. The full extinguishment times and amounts of agent used are plotted in Figure 2.

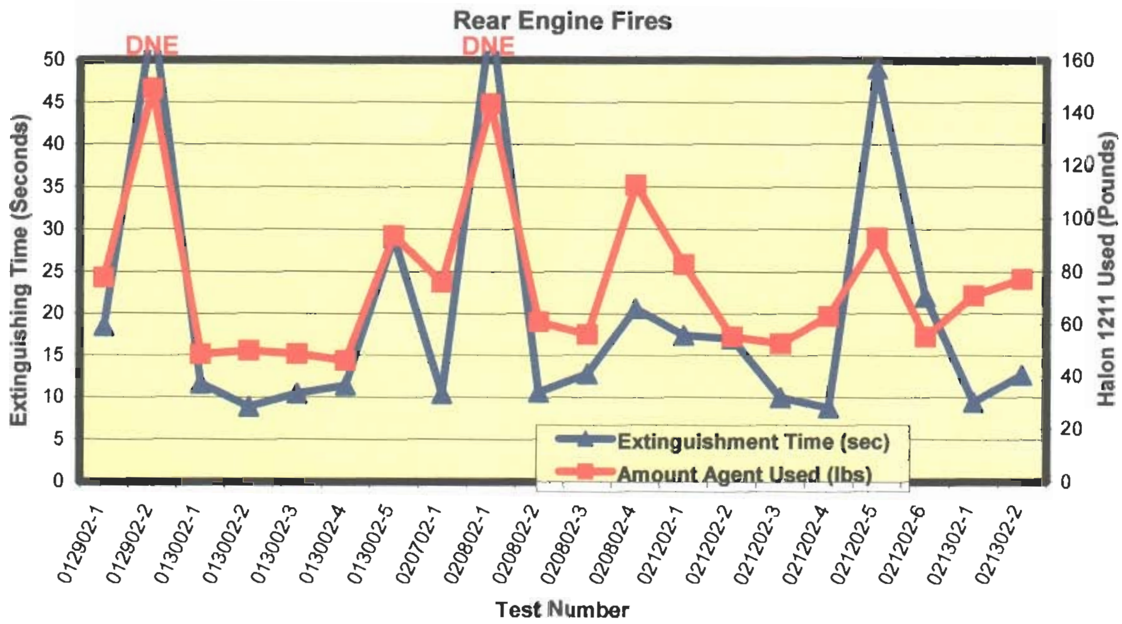

Figure 2. Summary of Extinguishment Times and Agent Used for Aft Engine Fires.

Access Panel Fires

80% of the fires were extinguished. All but one fire was extinguished within 35 seconds. Fires averaged 17.29 seconds extinguishment and 81.8 pounds of halon. The full extinguishment times and amounts of agent used are plotted in Figure 3.

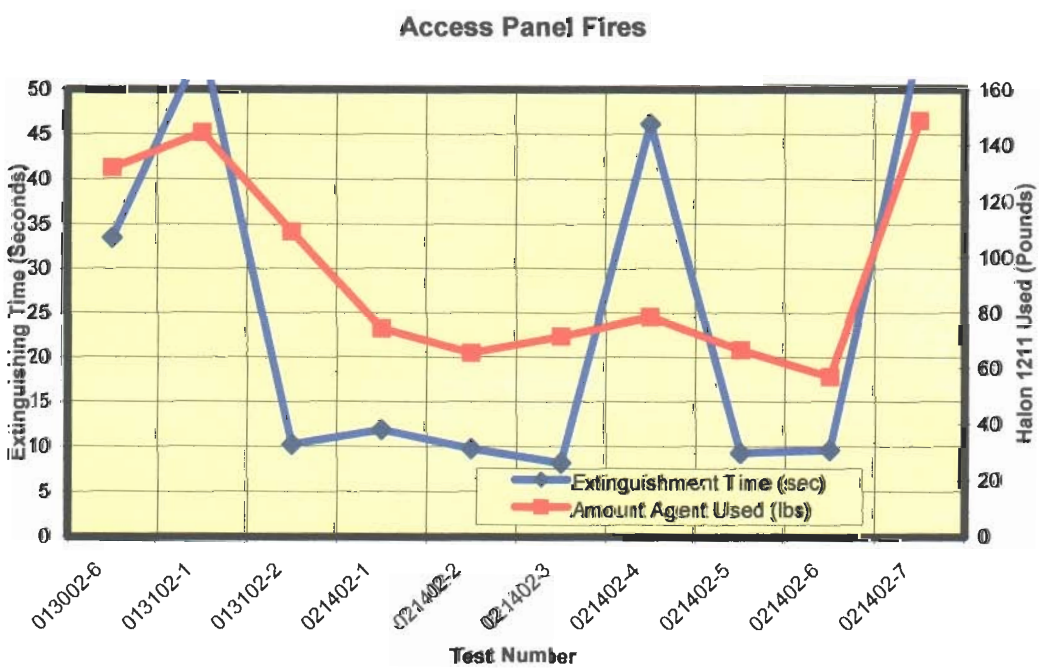

Figure 3. Extinguishment Times and Agent Used for Access Panel Fires.

Analysis

The fires (Figure 4 and 5) were regularly extinguished within 30 seconds using less than 100 lbs of Halon 1211. Two of twenty aft engine fires did not extinguish and two of ten access panel fires did not extinguish. Full extinguishment times for aft engine fires ranged from 8.75-50.93 seconds, with only one fire exceeding 30 seconds. The average time to extinguish an aft engine fire with Halon 1211 was 16.25 seconds. For access panel fires, full extinguishment times ranged ranged from 8.18 to 46.16 seconds, with only one fire taking greater than 30 seconds. The average time to extinguish an access panel fire was 17.29 seconds.

Of the aft engine fires that were extinguished, all but one consumed less than 100 pounds of Halon 1211 agent. That one used 112.6 pounds of agent, approximately 75% of the extinguisher capacity.

Of the access panel fires that were extinguished, all but one consumed less than 110 pounds of Halon 1211 agent. That one used 131.95 pounds of agent, approximately 88% of the extinguisher capacity.

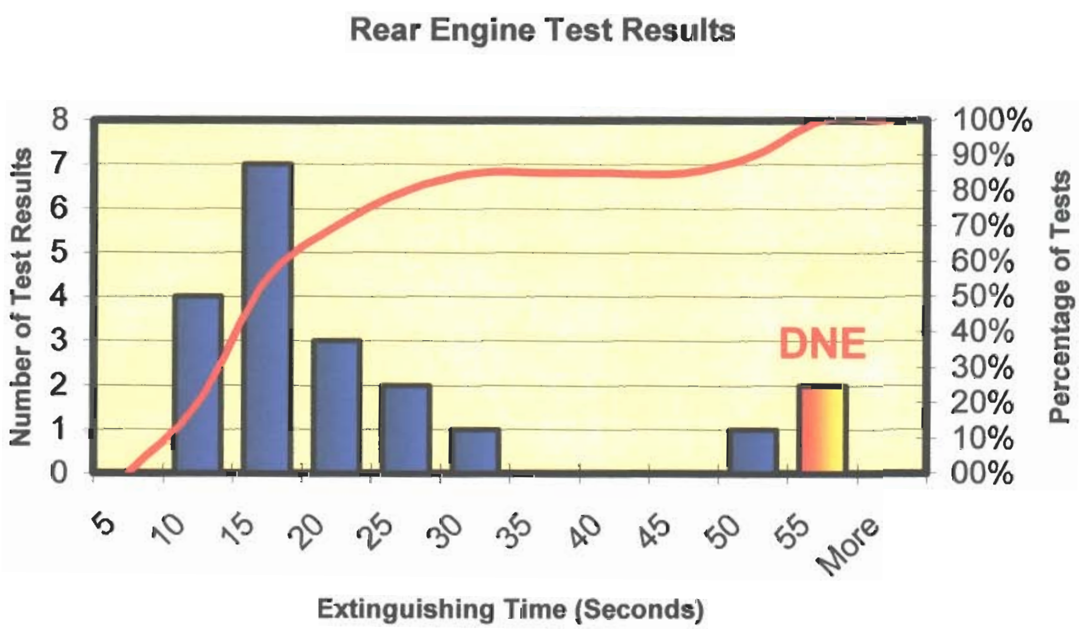

Figure 4. Histogram of Aft Engine Test Results

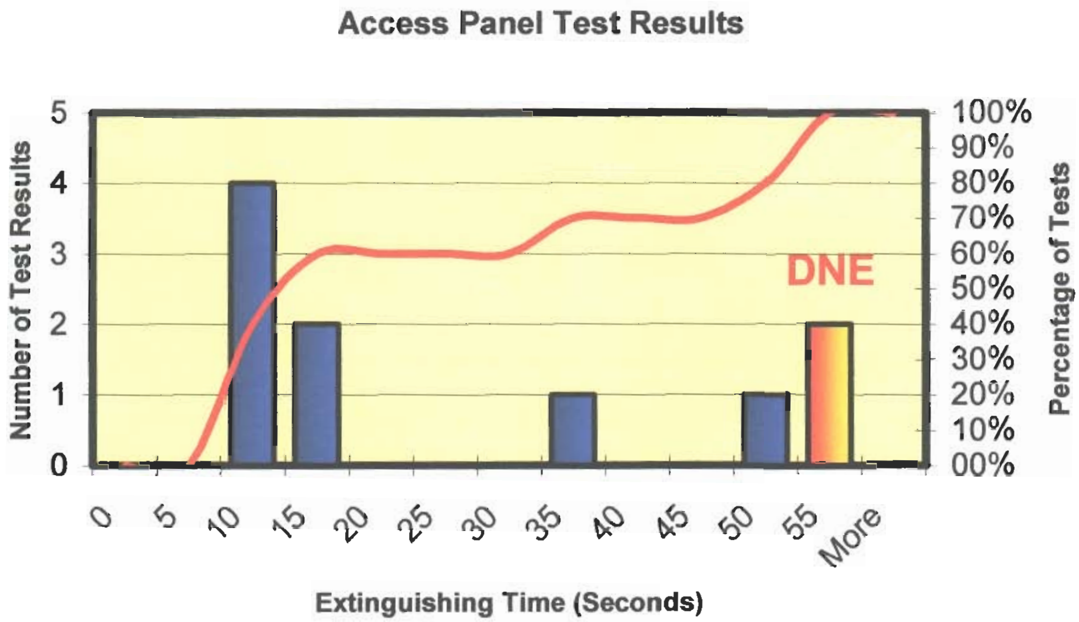

Figure 5. Summary of Access Panel Test Results

Fire Scenarios

Aft Engine Fires

The flightline fire extinguishers routinely extinguished fires in less than 30 seconds using less than 75% agent capacity.

Access Panel Fires

The flightline fire extinguishers routinely extinguished fires in less than 30 seconds using less than 75% agent capacity.

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i Minimum Performance Requirement for Air Force Flightline Fire Extinguishers: Extinguishing Performance Against 3-Dimensional And Hidden Fires, May 2002, AFRL-ML-TY-TR-02-4540 (ADA402968)

ii F100 Engine Nacelle Fire Fighting Test Mockup, July 2002, AFRL-ML-TY-TR-02-4604 (ADA405232)

APPENDIX I: Check List

Check List

Daily Inspections and Initial Preparations

1. ____ Complete base notification of pending fire tests.
2. ____ Insure two flight line fire extinguishers are fully serviced in accordance with T.O. 13F4-4-121 and pre-positioned at the test pan. Log the weight of the fully serviced fire extinguisher.
3. ____ Pre-position a fully serviced P-19 fire truck or equivalent and maintain on stand-by as a back-up firefighting vehicle near the test pan.
4. ____ Assign a primary and secondary firefighter.
5. ____ Collect meteorological data prior to fuel spilling to determine whether testing can proceed. Testing will not proceed if the wind velocity is greater than 5 knots.
6. ____ Move engine nacelle so that the aft section is in the predetermined proper position.
7. ____ Place two (2) video cameras adjacent to the fire, one behind the firefighter and one at perpendicular to the engine.
8. ____ Inspect thermocouples and data acquisition system. Ensure proper placement of the thermocouples in the nacelle and that thermocouples and data acquisition are working properly.
9. ____ Inspect ignition system. Ensure proper connection of the igniter hardware and ensure isolation from ground and continuity in the ignition circuit. Test and confirm operation of the igniter.
10. ____ Open fuel valves numbers 1, 2 and 3 to pressurize the system and check for leaks. Tighten fuel lines as appropriate to prevent leaks.

Pre-heat Phase

11. ____ Remove all non-essential personnel and assure all personnel involved in testing are in their assigned stations prior to approval for lighting the fire (as signaled by the AFRL Test Team Leader).
12. ____ Turn on data collection equipment.
13. ____ Turn on the video cameras at the beginning of the pre-heat phase and turn off cameras at the conclusion of the pre-heat phase. Ensure the display board contains all essential test information.
14. ____ The primary firefighter will don PPE and SCBA. A second firefighter will don PPE, serve as a backup firefighter and will be responsible for ignition of the test nacelle, if required.
15. ____ Turn on fuel valve number 3 and continue to flow fuel from fuel valve number 3 into the aft burner chamber.